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LOCATION, CHARACTERIZATION AND QUANTIFICATION OF HYDROACOUSTIC SIGNALS IN THE INDIAN OCEAN

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ABSTRACT

Data from three Indian Ocean hydroacoustic stations (Diego Garcia North, Diego Garcia South, and Cape Leeuwin) have been characterized and quantified for the calendar year 2002. These results were delivered to DTRA in the form a 2002 catalogue, and are briefly summarized here, with some additional consideration of their significance in the overall station characterization.

Background noise spectra for each station have been characterized for the entire year, and show distinct seasonal variations, as well as station-to-station differences. For the most part, Diego Garcia North is the quietest station, with Diego Garcia South being slightly noisier, and Cape Leeuwin being the noisiest station throughout most of the year. These observations in background noise variations help explain variations in some of the signals observed at each station.

Quantification of observed signals show that ship noise is a the most commonly observed signal at all three sites, with whale calls also being a frequent source of background signals. Airgunning is also observed frequently at all three stations, and can be quite disruptive when it is occurring. Cape Leeuwin is subject to a great deal of ice-related signals with this being by far the most dominant of the individually picked signals, with more than three times as many ice-related signals as T-waves observed. Diego Garcia North has by far the most P-wave/explosive signals observed, with the majority thought to be P-waves, though some explosions are distinguished.

A recent change in focus of the project has led to more detailed investigation of ice-related signals, as well as earthquake signals with high frequency energy. Our initial assessment indicates that ice-related signals represent a promising high-frequency source, with azimuth-based locations being confirmed by satellite data, and the origin of different signal types being better understood. Several large earthquakes have produced significant high frequency energy that has traveled through the Indian Ocean basin and will be utilized to study high-frequency blockage around Diego Garcia.

INTRODUCTION

Land based monitoring of earthquakes can be traced back many centuries and enormous scientific effort has been put into understanding the signals that seismographs record. In comparison, hydroacoustic monitoring of the oceans is a very recent development, and the water bourn T-wave phases of an earthquake were only identified in the early 1950's. The SOFAR (SOund Fixing And Ranging) channel in the ocean provides an excellent low-velocity wave-guide that can trap sound energy and transport it great distances with relatively little loss in signal strength. This makes hydroacoustic monitoring a powerful tool for detecting small acoustic signals originating in the ocean or along its seafloor and sea surface interfaces. Anthropogenic noises such as shipping and seafloor exploration tools are one of the most commonly observed signals. Whales also may use the SOFAR channel to communicate, and the calls of many different species can be observed regularly. In order to efficiently utilize hydrophones for explosion monitoring, it is important to have the 'typical' sounds observed well characterized. In this way, signals of concern can be compared to what is already known. Background noise levels of the stations, which can vary seasonally, are also important to characterize since they will impact the event magnitude that the station is able to observe (magnitude of completeness). To this end, we have characterized and quantified signals observed and background noise in the Indian Ocean for 2002.

Hydroacoustic data from three IMS stations in the Indian Ocean (Figure 1) have been analyzed for all days available in 2002, and through early 2003. These stations, Diego Garcia South (H08S), Diego Garcia North (H08N), and Cape Leeuwin (H01W) each have a triad of hydrophones moored ~ 2 km apart within the SOFAR channel, recording acoustic data at a sample rate of 250Hz. As part of contract DTRA01-01-C-0070, we have characterized and quantified all the observed signals on these three stations as well as quantifying and characterizing overall background noise. For each station, only one channel was used for picking events, since the close spacing of the phones means that signals look the same on all three channels.

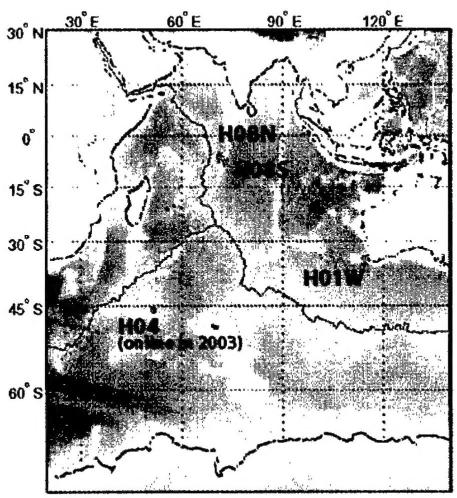

Figure 1. Location of IMS hydroacoustic stations in Indian Ocean. Diego Garcia North and South (HO8N and HO8S) and Cape Leeuwin (HO1W) are currently operational. Crozet (H04) is online, but still in a test phase. At each station there is a three hydrophone array, or triad, with an instrument separation of ~2 km.

Note that while data was studied through April 2003, the focus of this project was changed in the May-June 2003 time frame, and consequently the early 2003 results have not been assembled. However, the full catalogue and noise characterization for the calendar year 2002 has been assembled, and was delivered to DTRA in August 2003. Therefore results discussed below apply to data from calendar year 2002, most of which was assembled during the past contract year.

BACKGROUND NOISE CHARACTERISTICS

The background noise characteristics of all three IMS stations in the Indian Ocean have been characterized for all of 2002. Noise levels at hydrophone sites are controlled by a number of factors including proximity to shore (wave noise), weather variations and shipping in the area. The level of background noise is a critical factor in the ability of a station to observe specific events. As background noise increases, the detection sensitivity of the station decreases accordingly.

As shown in Figure 2, many noise sources are seasonal; therefore, it is important to characterize the noise for the full annual spectrum. This study has shown that in general Diego Garcia North is quieter than Diego Garcia South, and that both are quieter than Cape Leeuwin (Figure 3). However, daily noise variations at each station are substantial. In addition, variations in noise levels are frequency dependent. For instance, Cape Leeuwin (Figure 2) shows a seasonal increase in storm noise (very low frequency) during the Austral winter, while showing a simultaneous decrease in higher frequency noise bands likely due to a decrease in iceberg activity in Antarctica. Figure 3 shows a seasonal peak at 110 Hz at Diego Garcia North (see April), due to migration of blue whales through the area. Full characterizations of spectra for daily, monthly and yearly noise variations at each site can be found in the annual catalog for 2002.

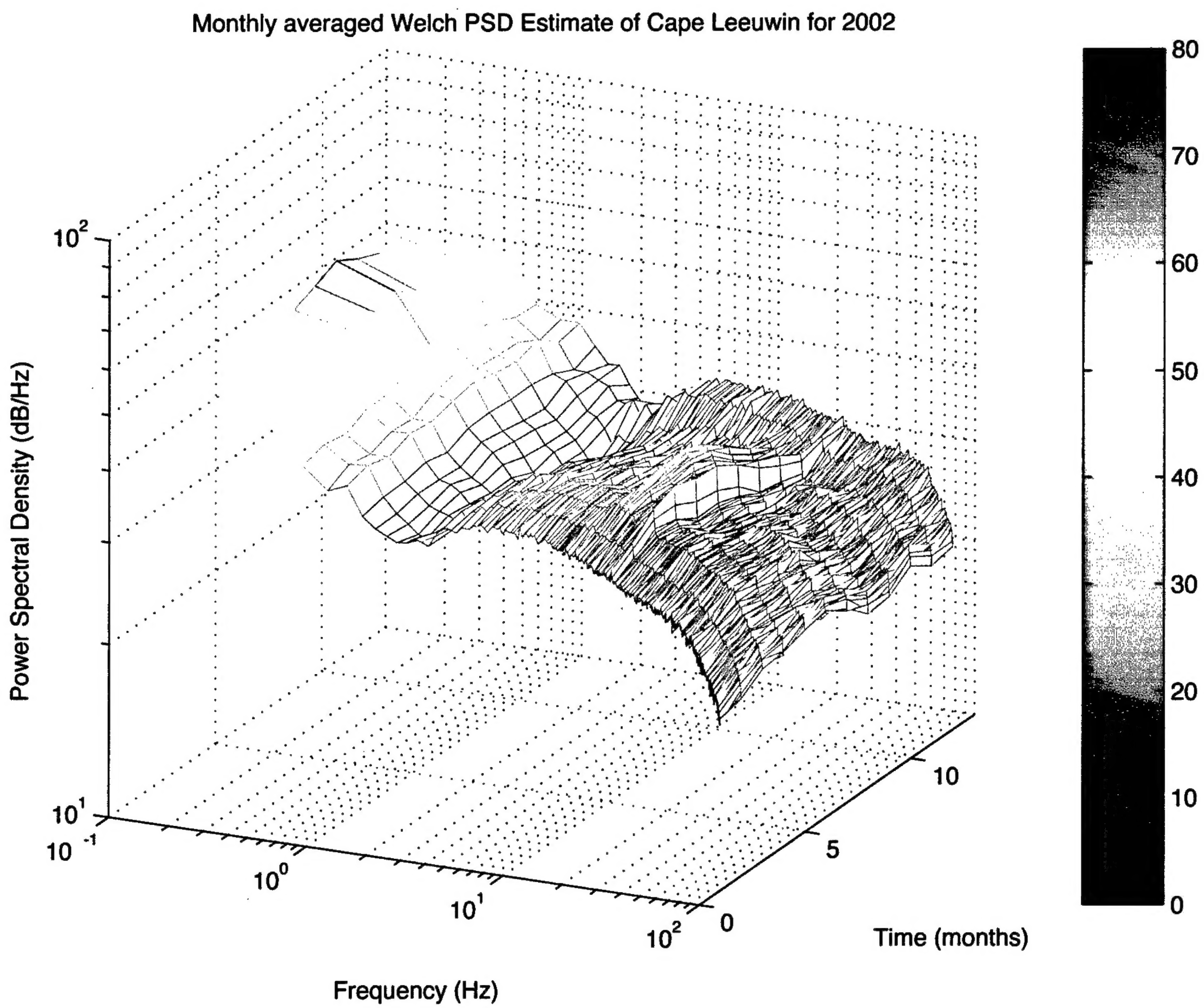

Figure 2. Monthly averages of power spectral density at Cape Leeuwin for 2002 showing the seasonal variation in noise.

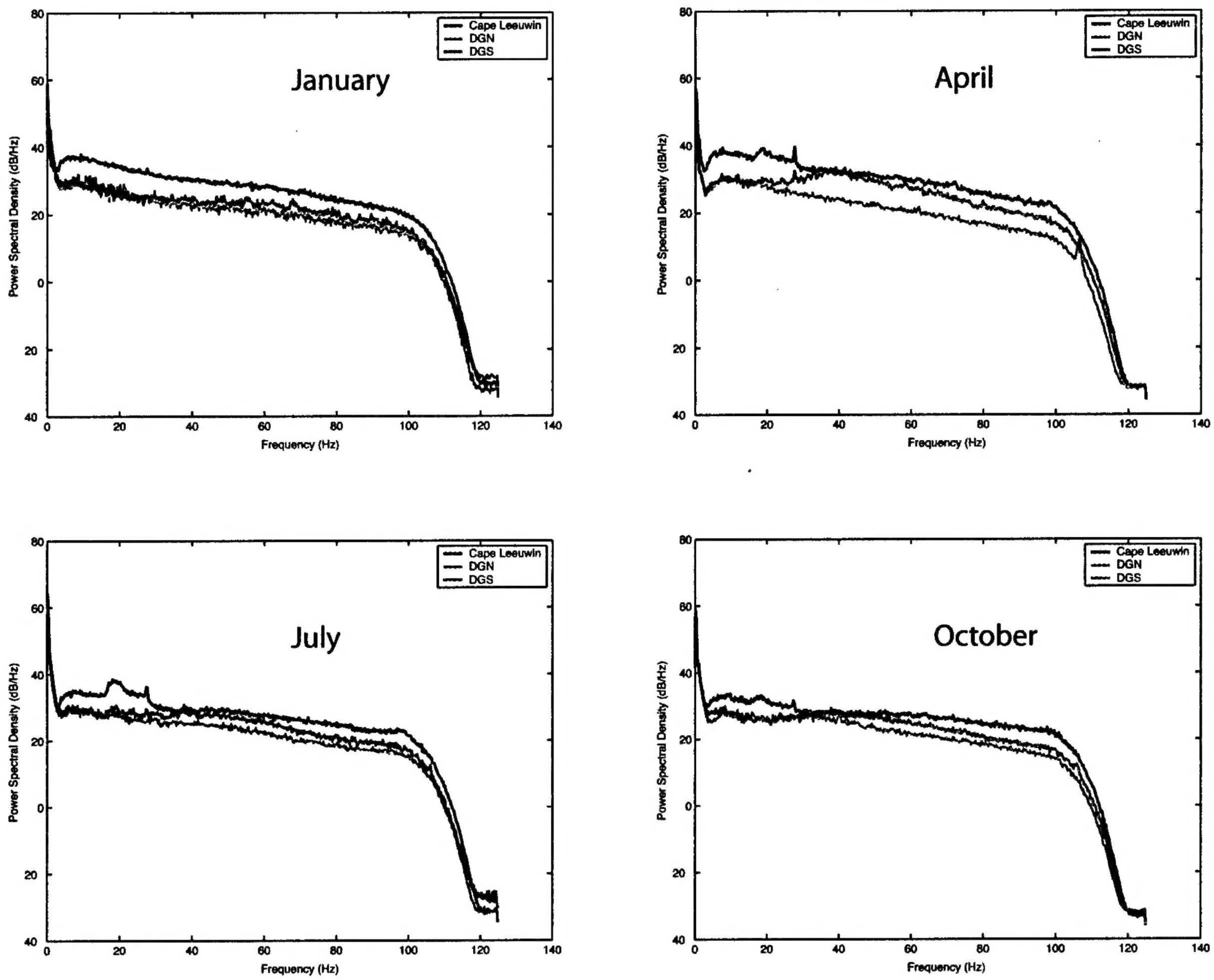

Figure 3:
Monthly averaged power spectral density for Diego Garcia North, Diego Garcia South and Cape Leeuwin during January, April, July and October 2002. Note that in general Cape Leeuwin is the noisiest station, with Diego Garcia North being the quietest, but there are clear seasonal variations, particularly within specific frequency bands. Cape Leeuwin is marked in blue, Diego Garcia South in red, and Diego Garcia North in green.

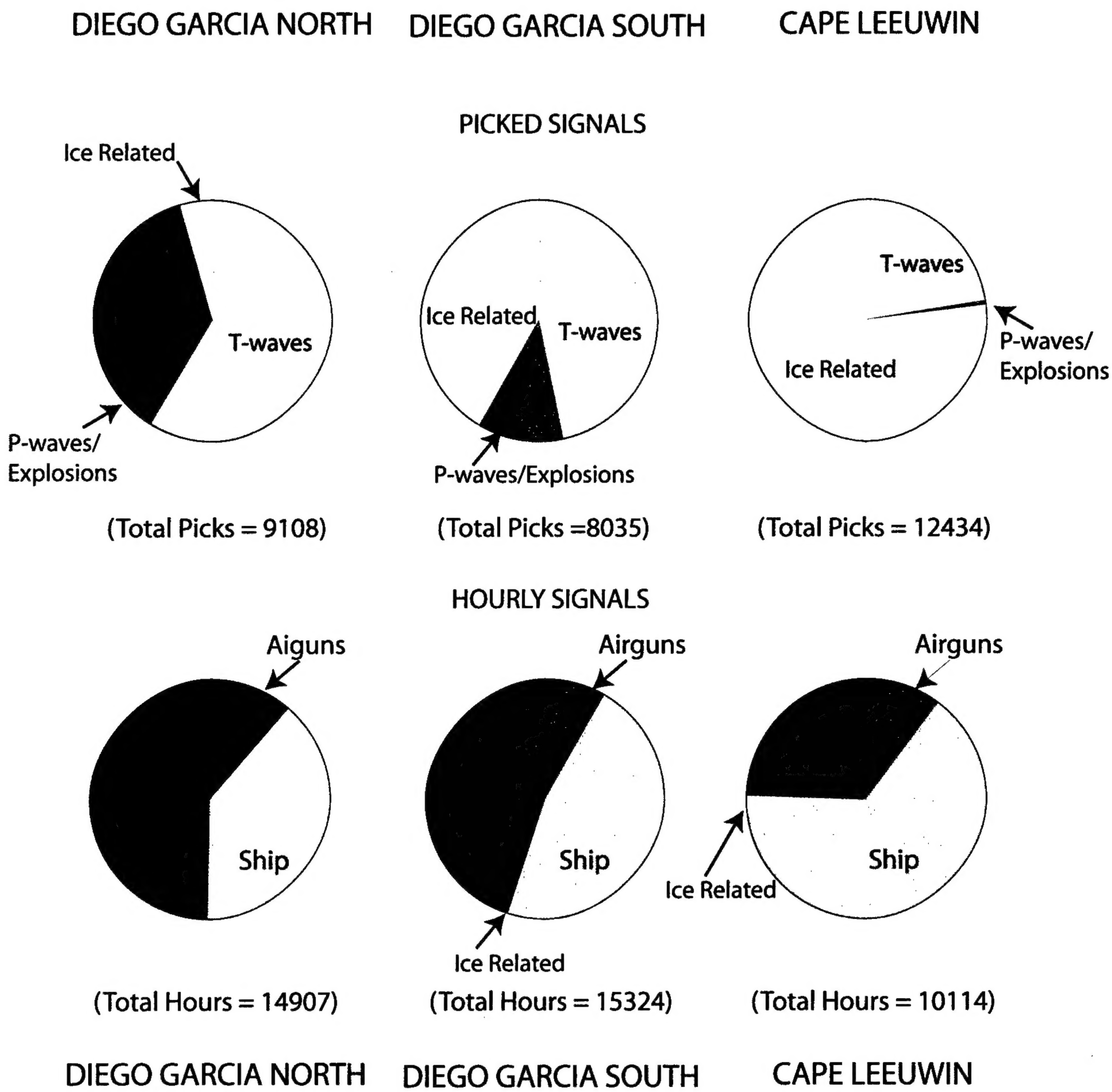

Figure 4:

Top pie charts show relative number of picks for different signals at stations Diego Garcia North, Diego Garcia South and Cape Leeuwin. This chart includes all signals for which individual arrival times were picked. Ice-related signals for picked events included iceberg movements, bloops and sharp signals, all believed to be related to ice movement in Antarctica. Total number of picks for all signals at each station is given below the pie chart.

Bottom pie charts show relative number of hours for different signals recorded at all three stations. This chart includes all signals which were assigned 'hourly' values - i.e. where an hour was marked as having the signal present or not present. The ice related signal is harmonic tremor associated primarily with ice-stream movement in Antarctica. Total number of hours of all signals at each station is given below the pie chart. Note, that since some hours contained more than one signal type, there are potentially more than 24 hours picked per day.

SIGNAL CHARACTERIZATION AND QUANTIFICATION

All observed signals have been identified based on their spectral character, as observed by an analyst. Individual non-impulsive signals such as T-waves or bloops were picked at their peak energy, and impulsive arrivals such as P-waves were picked at the beginning of the arrival. For frequently occurring signals where arrival times were not critical, or signals had no clear peak energy arrival time, the arrivals were categorized per hour. So individual hours were flagged as containing that signal, and hence a maximum of 24 observations could be made per day. This simplified the cataloging of repeating sources such as airguns or whales, and signals that were not impulsive such as ship noise. Catalogues of individual picks are available with the 2002 catalogue.

Figure 4 shows pie charts indicating the relative abundance of both picked and hourly signals at each station. The dominant signal varies from station to station quite notably. For Diego Garcia North the picked signals are dominated by T-waves, with a significant number of P-waves and possible explosions. Because explosions look quite similar in character to P-waves, they were categorized together. To distinguish between the two, cepstrum analysis needs to be done to identify the presence of a cepstrum peak (if the signal is from an explosion). It is thought that the majority of the picks in 2002 were P-waves (see 2002 annual catalogue for discussion and examples). There are numerous regional events near Diego Garcia that generate observable P-waves; however, since Diego Garcia is also a Naval base, it is possible that testing in the area could produce some of these impulsive signals. During the time period around Julian day 350, 2002 a series of events were observed in the vicinity of Diego Garcia that were thought likely to be explosions.

The significant number of P-wave observations at Diego Garcia North may be because it is the quietest station, and P-waves are often quite faint signals to observe hydroacoustically. Also observable at Diego Garcia North were a small number of ice-related signals, although the position of the station on the North side of the island means that the vast majority of these signals, coming from Antarctica, are blocked. The few signals that are observed tend to be in the 'unknown' category such as 'bloops' and 'sharp signals' (see 2002 report), that are thought to be ice-related, but have not definitively be shown to be so.

Hourly signals at Diego Garcia North were dominated by whales calls, followed by ship noise. In particular, a 110 Hz blue-whale call was so frequent that it would sometimes cause a spike in the monthly spectrum (see April in Figure 3). There is also a small, but significant amount of airgunning observed. Airgun activity, primarily from oil industry exploration ships, can be quite dominant when it is occurring, with 10-20 second intervals between impulsive broadband arrivals.

For picked arrivals at Diego Garcia South, T-waves were again the most frequently observed signal, but with ice-related signals following as a close second. There were significantly fewer P-wave/explosions observed. Hourly signals were again dominated by ship noise and whale calls, with slightly higher ship noise than whale calls. Again,

there is a small but significant amount of airgunning observed, as well as a tiny amount of ice-related noise. For the hourly signals, ice-related noise was cusped harmonic tremor associated with ice-stream movement on the coast of Antarctica.

For Cape Leeuwin picked arrivals, ice-related signals are by far the dominant arrival, reflecting the stations proximity and clear path to Antarctica. There were significantly fewer T-waves observed than at the Diego Garcia station, likely reflecting both the higher background noise levels, and the perhaps fewer earthquake source areas with direct paths to the stations. There were just a few P-wave/explosions observed at Cape Leeuwin probably due to the high background noise levels and low level of regional seismicity. For hourly signals at Cape Leeuwin ship noise was by far the most dominant signal, with smaller but significant whale call activity and airgunning. There is also a small, (but significantly larger than Diego Garcia stations), amount of ice-related signals, again related to ice-stream movement on the coast of Antarctica.

For more information on the many different signals observed, their temporal occurrence, and other details please see the 2002 catalogue.

FUTURE WORK

As of June 2003, the focus of this project was switched to looking for signals that could be used to study high frequency blockage as well as looking at ice-related signals to determine the feasibility of their use. In particular, we are looking for earthquake signals with significant high frequency energy (> 30 Hz, and preferably > 50 Hz) that could be used to study blockage. Large earthquakes are looking promising for examining high frequency blockage of events, with significant changes in the spectral slope between arrivals at Diego Garcia North and Diego Garcia South (see Figure 5)

We are also investigating ice-related signals, particularly those observed at multiple stations and with high-frequency energy (e.g. Figure 6). So far the results are encouraging, with numerous high frequency ice-related signals observed at multiple stations. Combined azimuths from Diego Garcia South and Cape Leeuwin provide reasonably accurate locations along coastal Antarctica, and have been correlated with specific icebergs and specific ice-streams using satellite data. A signal previously characterized as 'tremor', which was of unknown origin, has been associated exclusively with the movement of coastal ice-streams.

Improved characterization of the events is helping confirm their locations and source, which in turn will help to better understand their propagation characteristics. Once we have obtained enough appropriate and locatable examples, we will begin analysis and modeling to understand their propagation and circumstances surrounding any associated signal loss.

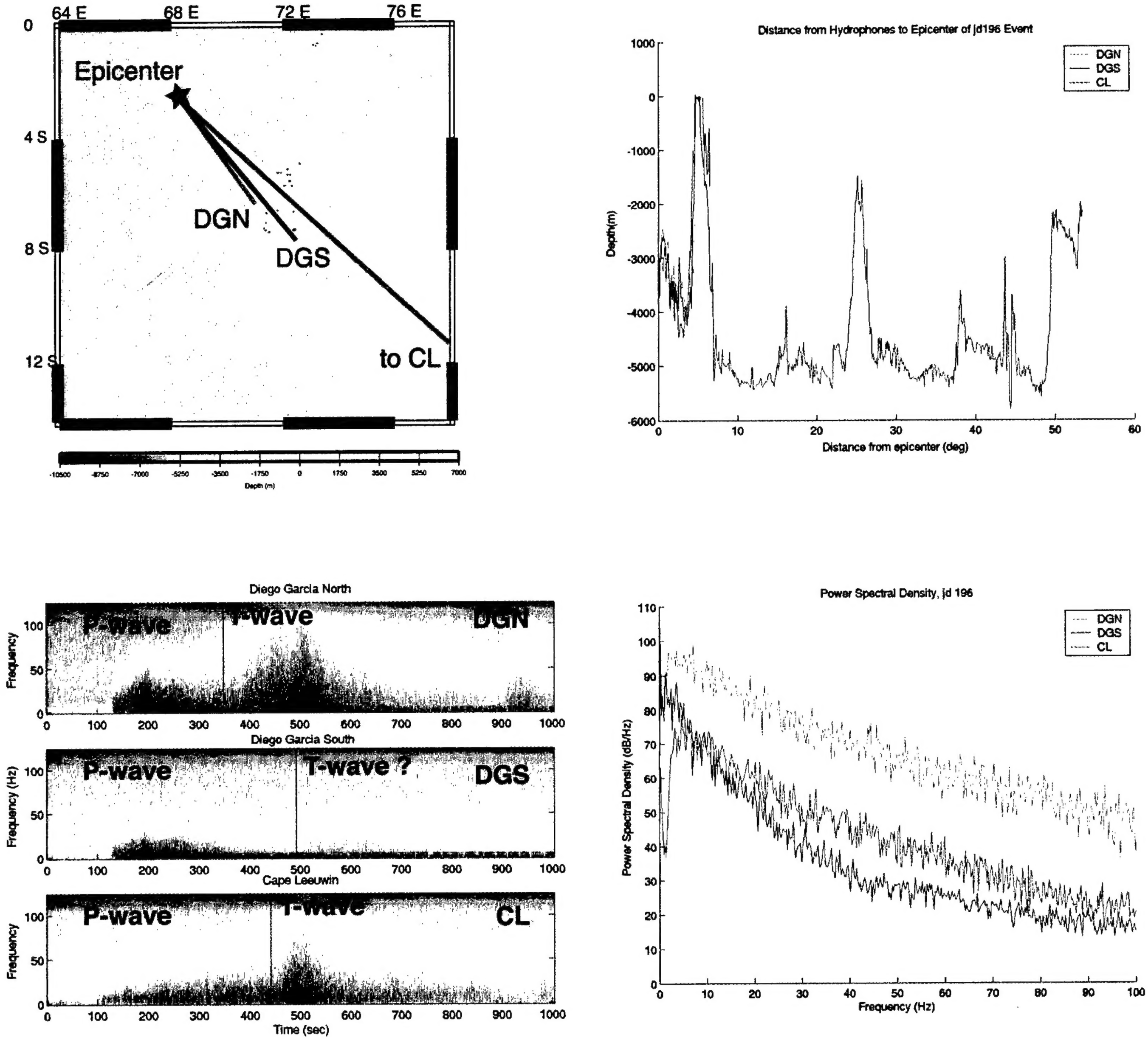

Figure 5:

Top left: Ray paths of T-waves over shallow topography from large (7.6 Mw) earthquake on Julian Day 196 (2002) to each hydrophone station. **Top right:** Topography along paths from earthquake epicenter to each hydrophone station. Note very similar topographic peaks for Diego Garcia South and Cape Leeuwin. **Bottom Left:** Spectrogram for earthquake arrival at all three stations. Thin vertical black line indicates predicted start time of T-wave arrival. Despite very similar shallow topographic paths, very little T-wave energy reaches Diego Garcia South, while considerable T-wave energy reaches Cape Leeuwin. **Bottom Right:** Power Spectral Density for each hydrophone station during earthquake arrival, again displaying that very little high frequency T-wave energy is observed at Diego Garcia South.

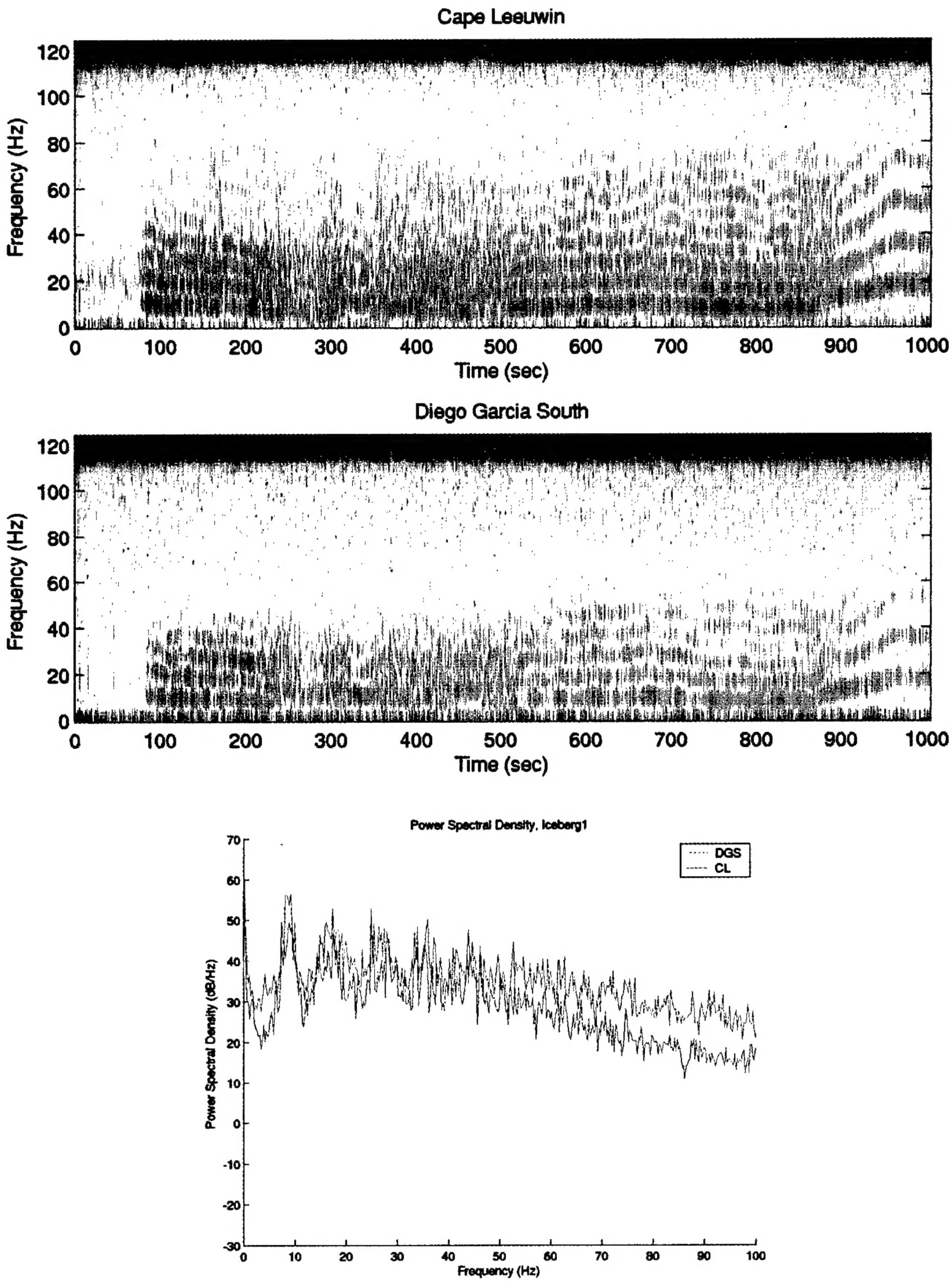

Figure 6:

Top two plots show spectrograms for the same iceberg arrival at Cape Leeuwin and Diego Garcia South. Note the higher frequency harmonics are attenuated at Diego Garcia South. The bottom plot shows the corresponding power spectral density for the arrival at both stations. A relative change of slope above ~ 50 Hz is apparent between the two sites, confirming the attenuation of higher frequency arrivals at Diego Garcia South.